WHAT IS CLAIMED IS:

1.   In a Noise Feedback Coding (NFC) system, a method of efficiently searching N predetermined Vector Quantization (VQ) codevectors for a preferred one of the N VQ codevectors to be used in coding a speech or audio signal, comprising the steps of:

(a)   predicting the speech signal to derive a residual signal;

(b)   deriving a ZERO-INPUT response error vector common to each of the N VQ codevectors;

(c)   deriving N ZERO-STATE response error vectors each based on a corresponding one of the N VQ codevectors; and

(d)   selecting the preferred one of the N VQ codevectors as the VQ output vector corresponding to the residual signal based on the ZERO-INPUT response error vector and the N ZERO-STATE response error vectors.

2.   The method of claim 1, further comprising the step of:

separately combining the ZERO-INPUT response error vector with each one of the N ZERO-STATE response error vectors to produce an error energy value corresponding to each one of the N VQ codevectors, wherein step (d) comprises selecting one of the N VQ codevectors corresponding to a minimum error energy value as the preferred one of the N VQ codevectors.

3.   The method of claim 1, wherein step (b) comprises the steps of:

(b)(i)   deriving an intermediate vector based on the residual signal;

(b)(ii) predicting the intermediate vector to produce a predicted intermediate vector;

(b)(iii) combining the intermediate vector with the predicted intermediate vector and a noise feedback vector to produce the ZERO-INPUT response error vector; and

(b)(iv) filtering the ZERO-INPUT response error vector to produce the noise feedback vector.

4. The method of claim 3, wherein:

step (b)(ii) comprises long-term predicting the intermediate vector to produce the predicted intermediate vector; and

step (b)(iv) comprises long-term filtering the ZERO-INPUT response error vector to produce the noise feedback vector.

5. The method of claim 3, wherein:

step (b)(ii) comprises predicting the intermediate vector based on an initial predictor state corresponding to a previous preferred codevector; and

step (b)(iv) comprises filtering the ZERO-INPUT response error vector based on an initial filter state corresponding to the previous preferred codevector.

6. The method of claim 1, wherein step (b) comprises the steps of:

(b)(i) combining the residual signal with a noise feedback signal to produce an intermediate vector;

(b)(ii) predicting the intermediate vector to produce a predicted intermediate vector;

(b)(iii) combining the intermediate vector with the predicted intermediate vector to produce an error vector; and

(b)(iv) filtering the error vector to produce the noise feedback vector.

7. The method of claim 6, wherein:

step (b)(ii) comprises long-term predicting the intermediate vector to produce the predicted intermediate vector; and

step (b)(iv) comprises short-term filtering the error vector to produce the noise feedback vector.

8.   The method of claim 6, wherein:

step (b)(ii) comprises predicting the intermediate vector based on an initial predictor state corresponding to a previous preferred codevector; and

step (b)(iv) comprises filtering the error vector based on an initial filter state corresponding to the previous preferred codevector.

9.   The method of claim 1, wherein step (c) comprises the steps of:

(c)(i)   separately filtering an error vector associated with each of the N VQ codevectors to produce a ZERO-STATE input vector corresponding to each of the N VQ codevectors; and

(c)(ii)   separately combining each ZERO-STATE input vector from step (c)(i) with the corresponding one of the N VQ codevectors, to produce the N ZERO-STATE response error vectors.

10.   The method of claim 9, wherein the filtering in step (c)(i) comprises short-term filtering of the error vector.

11.   ' The method of claim 9, wherein the filtering in step (c)(i) is based on an initially zeroed filter state, and wherein step (c) further comprises the step of:

(c)(iii) zeroing the filter state to produce the initially zeroed filter state before each pass through step (c)(i).

12.   The method of claim 1, wherein step (c) comprises the steps of:

(c)(i)   separately combining each of the N VQ codevectors with a corresponding one of N filtered, ZERO-STATE response error vectors to produce the N ZERO-STATE response error vectors; and

(c)(ii) separately filtering each of the N ZERO-STATE response error vectors to produce the N filtered, ZERO-STATE response error vectors.

13.   The method of claim 12, wherein the filtering in step (c)(ii) comprises short-term filtering.

14.   The method of claim 12, wherein the filtering in step (c)(ii) is based on an initially zeroed filter state, and wherein step (c) further comprises the step of:

(c)(iii) zeroing the filter state to produce the initially zeroed filter state before each pass through step (c)(ii).

15.   The method of claim 12, further comprising the steps of:

deriving a gain value based on the speech signal; and

scaling at least some of the N VQ codevectors based on the gain value.

16.   The method of claim 12, further comprising the steps of:

deriving a set of filter parameters based on the speech signal; and

filtering the N VQ codevectors in step (c)(ii) based on the set of filter parameters.

17.   The method of claim 12, wherein the speech signal comprises a sequence of speech vectors each including a plurality of speech samples, the method further comprising the steps of:

deriving a set of filter parameters based on the speech signal once every T speech vectors, where T is greater than one; and

performing step (c) only when a set of filter parameters is derived the once every T speech vectors, whereby a same set of N

ZERO-STATE response error vectors is used in selecting each of T preferred codevectors in step (d) corresponding to the T speech vectors.

18.   The method of claim 1, wherein the speech signal comprises a sequence of speech vectors each including a plurality of speech samples, the method further comprising the step of:

performing step (c) once every T speech vectors, where T is greater than one, whereby a same set of N ZERO-STATE response error vectors is used in selecting T preferred codevectors in step (d) corresponding to the T speech vectors.

19.   The method of claim 1, wherein the speech signal comprises a sequence of speech vectors each including a plurality of speech samples, the method further comprising the steps of:

deriving a gain value based on the speech signal once every M speech vectors, where M is greater than one;

scaling the N VQ codevectors the once every M speech vectors based on the gain value; and

deriving the N ZERO-STATE response error vectors in step (c) only when the gain value is derived the once every M speech vectors, whereby a same set of N ZERO-STATE response error vectors is used in selecting each of M preferred codevectors in step (d) corresponding to the M speech vectors.

20.   A method of deriving a final set of N codevectors useable for prediction residual quantization of a speech or audio signal in a Noise Feedback Coding (NFC) system, comprising the steps of:

(a)   deriving a sequence of residual signals corresponding to a sequence of input speech training signals;

(b)   quantizing each of the residual signals into a corresponding preferred codevector selected from an initial set of N codevectors to minimize a quantization error associated with the preferred codevector, thereby producing a sequence of preferred codevectors corresponding to the sequence of residual signals;

(c)   deriving a total quantization error energy for one of the N codevectors based on the quantization error associated with each occurrence of the one of the N codevectors in the sequence of preferred codevectors; and

(d)   updating the one of the N codevectors to minimize the total quantization error energy.

21.   The method of claim 20, further comprising the step of:

(e)   repeating steps (c) and (d) for each of the codevectors in the set of N codevectors, thereby updating each of the N codevectors to produce an updated set of N codevectors.

22.   The method of claim 21, further comprising the step of:

(f)   continuously repeating steps (b) – (e) using each updated set of N codevectors as the initial set of N codevectors in each next pass through steps (b) – (e), until the final set of N codevectors is derived.

23.   The method of claim 22, wherein step (f) comprises the steps of:

deriving a quantization error energy measure associated with each updated set of N codevectors from step (e);

selecting an updated set of N codevectors from step (e) as the final set of N codevectors when an error energy difference between

the quantization error energy measure associated with
the final set of N codevectors, and

the quantization error energy measure associated with a previously updated set of N codevectors is within a predetermined error energy range.

24.   The method of claim 20, wherein each of the codevectors has a vector-dimension of one, whereby each of the codevectors represents a scalar quantity.

25.   The method of claim 22, wherein each of the codevectors has a vector-dimension greater than one, whereby each of the codevectors represents a vector quantity.

26.   The method of claim 20, wherein step (b) comprises:

(b)(i)   deriving a ZERO-INPUT response error vector common to each of the N codevectors;

(b)(ii)   deriving N ZERO-STATE response error vectors each corresponding to one of the N codevectors;

(b)(iii) separately combining the ZERO-INPUT response vector with each of the ZERO-INPUT response error vectors to produce N quantization error energy values each corresponding to one of the N codevectors; and

(b)(iv) selecting one of the N codevectors corresponding to a minimum one of the N quantization error energy values as the preferred codevector.

27.   The method of claim 26, wherein step (b)(ii) comprises the steps of:

combining each of the N codevectors with a corresponding feedback signal to produce the N ZERO-STATE response vectors; and

separately short-term filtering each of the N ZERO-STATE response vectors to produce each said corresponding feedback signal.

28.   The method of claim 27, wherein step (d) comprises solving the equation below for y_j

$$\left[\sum_{n \in N_j} g^2(n) \mathbf{H}^T(n) \mathbf{H}(n) \right] y_j = \left[\sum_{n \in N_j} g(n) \mathbf{H}^T(n) qzi(n) \right],$$

where

y_j represents an updated codevector resulting from updating the one of the N codevectors to minimize the total quantization error energy;

g(n) represents a codevector scaling factor,

H(n) represents a codevector filter transfer function, and

qzi(n) represents a ZERO-INPUT response.

29.   A Noise Feedback Coding (NFC) system for fast searching N Vector Quantization (VQ) codevectors stored in a VQ codebook for a preferred one of the N VQ codevectors to be used for coding a speech or audio signal, comprising the steps of:

predicting logic adapted to predict the speech signal to derive a residual signal;

a ZERO-INPUT filter structure adapted to derive a ZERO-INPUT response error vector common to each of the N VQ codevectors in the VQ codebook;

a ZERO-STATE filter structure adapted to derive N ZERO-STATE response error vectors each based on a corresponding one of the N VQ codevectors in the VQ codebook; and

a selector adapted to select the preferred one of the N VQ codevectors as a VQ output vector corresponding to the residual signal based on the ZERO-INPUT response error vector and the N ZERO-STATE response error vectors.

30.   The system of claim 29, further comprising:

a combiner adapted to separately combine the ZERO-INPUT response error vector with each one of the N ZERO-STATE response error vectors to produce an error energy value corresponding to each of the N VQ codevectors, the selector being adapted to select one of the N VQ codevectors corresponding to a minimum error energy value as the preferred one of the VQ codevectors.

31. The system of claim 29, wherein the ZERO-INPUT filter structure comprises:

intermediate vector deriver adapted to derive an intermediate vector based on the residual signal;

a predictor adapted to predict the intermediate vector to produce a predicted intermediate vector;

combining logic adapted to combine the intermediate vector with the predicted intermediate vector and a noise feedback vector to produce the ZERO-INPUT response error vector; and

a filter adapted to filter the ZERO-INPUT response error vector to produce the noise feedback vector.

32. The system of claim 31, wherein:

the predictor is adapted to long-term predict the intermediate vector; and

the filter is adapted to long-term filter the ZERO-INPUT response error vector.

33. The system of claim 31, wherein:

the predictor is adapted to predict based on an initial predictor state corresponding to a previous preferred codevector; and

the filter is adapted to filter based on an initial filter state corresponding to the previous preferred codevector.

34.   The system of claim 29, wherein the ZERO-INPUT filter structure comprises:

a first combiner adapted to combine the residual signal with a noise feedback signal to produce an intermediate vector;

a predictor adapted to predict the intermediate vector to produce a predicted intermediate vector;

a second combiner adapted to combine the intermediate vector with the predicted intermediate vector to produce an error vector; and

a filter adapted to filter the error vector to produce the noise feedback vector.

35.   The system of claim 34, wherein:

the predictor is adapted to long-term predict the intermediate vector to produce the predicted intermediate vector; and

the filter is adapted to short-term filter the error vector to produce the noise feedback vector.

36.   The system of claim 34, wherein

the predictor is adapted to predict based on an initial predictor state corresponding to a previous preferred codevector, and

the filter is adapted to filter based on an initial filter state corresponding to the previous preferred codevector.

37.   The system of claim 29, wherein the ZERO-STATE filter structure comprises:

a filter adapted to separately filter an error vector associated with each of the N VQ codevectors to produce a ZERO-STATE input vector corresponding to each of the N VQ codevectors; and

a combiner adapted to separately combine each ZERO-STATE input vector produced by the filter with the corresponding one of the N

VQ codevectors, to produce the N ZERO-STATE response error vectors.

38.   The system of claim 37, wherein the filter is adapted to short-term filter the error vector.

39.   The system of claim 37, further comprising filter zeroing logic adapted to zero the filter state to produce an initially zeroed filter state before the filter filters each of the N error vectors.

40.   The system of claim 29, wherein the ZERO-STATE filter structure comprises:

a combiner adapted to separately combine each of the N VQ codevectors with a corresponding one of N filtered, ZERO-STATE response error vectors to produce the N ZERO-STATE response error vectors; and

a filter adapted to separately filter each of the N ZERO-STATE response error vectors to produce the N filtered, ZERO-STATE response error vector.

41.   The system of claim 40, wherein the filter is adapted to short-term filter each of the N ZERO-STATE response error vectors.

42.   The system of claim 40, further comprising filter zeroing logic adapted to zero the filter state to produce an initially zeroed filter state before the filter filters each of the N error vectors.

43.   The system of claim 40, further comprising:

gain deriving logic adapted to derive a gain value based on the speech signal; and

a gain scaling unit adapted to scale at least some of the N VQ codevectors based on the gain value.

44.   The system of claim 40, further comprising:

filter parameter deriving logic adapted to derive a set of filter parameters based on the speech signal; and

a filter adapted to filter the N VQ codevectors based on the set of filter parameters.

45.   The system of claim 40, wherein:

the speech signal comprises a sequence of speech vectors each including a plurality of speech samples;

the filter parameter deriving logic is adapted to update the set of filter parameters based on the speech signal once every T speech vectors, where T is greater than one; and

the ZERO-STATE filter structure is adapted to derive the N ZERO-STATE response error vectors only when the set of filter parameters is updated the once every T speech vectors.

46.   The system of claim 29, wherein the speech signal comprises a sequence of speech vectors each including a plurality of speech samples, the ZERO-STATE filter structure being adapted to derive the N ZERO-STATE response error vectors once every T speech vectors, whereby a same set of N ZERO-STATE response error vectors is used in selecting T preferred codevectors corresponding to the T speech vectors.

47.   The system of claim 29, wherein the speech signal comprises a sequence of speech vectors each including a plurality of speech samples, the system further comprising:

gain deriving logic adapted to derive a gain value based on the speech signal once every M speech vectors, where M is greater than one; and

a gain scaling unit adapted to scale the N VQ codevectors once every M speech vectors based on the gain value, wherein the ZERO-STATE filter structure is adapted to derive the N ZERO-STATE response error vectors once every M speech vectors, whereby a same set of N ZERO-STATE response error vectors is used in selecting M preferred codevectors corresponding to the M speech vectors.